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Material - Aluminum - 2024-T6

Effect of Aftificial Aging on Rivet Strengths

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Effect of Artificial Aging on Rivet Strengths

Abstract

Conventional "ice-box" stored as quenched 2024 aluminum alloy rivets are troublesome in production because of their instability at room temperatures. The instability results from natural aging and resulting hardening which interfers with rivet usefulness. Artificial aging at some elevated temperature was considered as a means for stabilizing rivet properties throughout their production and use. Preliminary tests indicated that satisfactory material properties could be developed in 2024 rivets by aging them at 398°F for 3-3/4 hours, however, question remained regarding the reproducibility of artificial aging results with commercially produced 2024 aluminum alloy rivet wire. A lengthy test program involving a wide variety of rivet and rivet joint configurations was conducted to verify the validity of the artificially aged rivet and its reproducibility in practice. These tests indicated that the properties spread resulting from a combination of composition, aging, and use conditions resulted in inconsistency in joint behavior, and consequently the artificially aged 2024 aluminum rivet was abandoned.

References: 1. Stier, H. H., Langford, G. J., Turner, H. C., "Test of Artificially Aged 2024 Aluminum Alloy Rivets," General Dynamics/Convair Report MP 57-922, San Diego, California, 20 June 1958 (Reference attached).

2. Miller, R. A. Steurer, W. H., "Test of Artificially Aged 2024 Aluminum Alloy Rivets," General Dynamics/Convair Report MP 57-922, App.I, San Diego, California, 28 January 1959 (Reference attached).

CONVAIR
A DIVISION OF GENERAL DYNAMICS CORPORATION
SAN DIEGO

STRUCTURES-MATERIALS LABORATORIES

REPORT 57-922
DATE 20 June 1958
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T.N. 57-922
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TITLE

REPORT NO. 57-922

TITLE: TEST OF ARTIFICALLY AGED 2024 ALUMINUM ALLOY RIVETS

MODEL: REA 8218

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FOREWORD

During the past 1 1/2 years the Structures Design Group has submitted seven test requests* to the Materials and Processes Laboratory to obtain data relative to the substitution of over-aged 2024 aluminum alloy rivets for "ice box" rivets. Except for the original preliminary survey (see Report No. 56-191), no formal report was made for any of the subsequent test requests due to the continuous pressure for obtaining additional data as quickly as possible to expand or complete the picture being developed.

Rejection by CAA of Convair's original application for permission to use over-aged rivets in restricted areas of the Convair 440 created the need for a rapid increase in experience with this rivet if an early second application was to be submitted before phase-out of the 440 program.

Since CAA decided to demand a wider scope of data than was specified when the idea of over-aged rivets was originally presented to them, the Convair Structures Design Group asked that many more combinations of rivet sizes, rivet head shapes and sheet sizes be investigated as soon as possible. The new demands emphasized countersunk rivets which proved to be the greatest stumbling block in this project. To determine the optimum conditions for sufficient joint strength without excessive shop head cracking, various aging cycles, rivet shank protrusions, degrees of upsetting of shop heads, squeezing tools, shank chamfer, etc., were evaluated for 100°-head rivets. In the final phase of this project limited production experience with the over-aged rivets was obtained when the details of heat treatment of rivets and fabrication of test panels had been agreed to by both the Structures Design Group and the Production Department.

Even the best of the data obtained for the test requests listed above were repeatedly marginal; that is, most of the data were satisfactory except for a few individual specimens in a group and occasionally an entire group of six identical specimens which exhibited shear strength values considerably lower than the ANC-5 requirements for "ice box" rivets.

This report presents the final phase of this project: a recheck on many of the test groups involving 100°-head rivets which, in previous tests, had displayed an unacceptable degree of spread. The results of previous tests of aged rivets are given in appendices to this report. **

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* T.N.'s 56-191, 56-699, 57-201, 57-122, 57-479, 57-614, 57-922.

** Appendices are not included at present, but will be added when available.

OBJECT:

The object of this test is to determine whether 2024-T6 rivets [1] can be substituted for 2024-T31 rivets [2] in riveted joints.

CONCLUSIONS:

1. The ultimate shear strengths of riveted joints incorporating 100°-head 2024-T6 rivets [1,3] are approximately equal to the ANC-5 allowable values * for similar joints employing 2024-T31 rivets[2] (within ± 6%) except in the rivet-sheet combinations with low t/D ratios; the latter may have ultimate strengths 25% above the ANC-5 values.

2. The yield strength in shear of riveted joints incorporating 100°-head 2024-T6 rivets[1,3] vary from 12% above to 21% below the ANC-5 allowable values* for similar joints employing 2024-T31 rivets.

3. Artificially aged 2024-T6 rivets[1] may have the upset heads driven to 1.33-1.40 rivet diameters without producing rejectable cracked heads if the initial shank protrusion is 1.05 - 1.15 rivet diameters.

RECOMMENDATION:

The adoption of artificially aged 100°-head 2024-T6 rivets[1] is not recommended because the data for this and all previous tests have exhibited too much "spread" involving an excessive proportion of values much lower than those specified by ANC-5.

TEST SPECIMENS:

The specimens used in these tests were of the single lap-joint type which, when tested in tension, result in a shear load on the fastener. The joints had two fasteners positioned along the longitudinal center line of the joint. Sketches of the test specimens are shown at the bottom of Tables I and II. The variable dimensions of the specimens are given in these tables which also contain the test results.

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1. 2024 rivets artificially aged for 3 3/4 hrs. at 398°F. to 44 - 46 KSI shear strength before driving.

2. 2024 rivets maintained in solution treated condition until driving ("ice box") rivets.

3. Initial shank protrusion equal to 1.05 - 1.15 rivet diameters; upset head diameter equal to 1.33 - 1.40 rivet diameters.

* "Strength of Metal Aircraft Elements", ANC-5 Bulletin, p. 122-123 (March 1955).

Specimens were table-sawed from riveted panels (each panel yielded six specimens of dimensions given in Tables I and II). These panels were bolted together for drilling and countersinking of the rivet holes and were unbolted to remove chips between the faying surfaces. The panels were bolted together again for driving the rivets. Portable air tools were employed in drilling and countersinking. The depth of countersinking was controlled with stops on the countersink and with gauges in the form of 100°-head rivets which could be slipped into the countersunk holes to measure the depth of the recess.

Solution treatment of rivets is given below:

TEMPERATURE	TIME AT TEMPERATURE	FURNACE
910° - 918°F.	35 minutes	Recirculating Air

Solution treated rivets were quenched in water at 70°F. upon removal from the furnace.

For artificial aging the rivets were heated to 398°F. for 3-3/4 hours in a recirculating air furnace about 10 to 15 minutes after quenching from 910° - 918°F. The effectiveness of heat treatment was checked by means of control rivets which were tested in double-shear in a fixture designed for that purpose.

"Ice box" rivets were placed on dry ice in a Dewar flask within 3 minutes after quenching from 915°-920°F. The rivets were dried with an absorbent gauze in the 3 minute interval between quenching and freezing. The rivets were at - 52°F. (as measured by a copper-constantan thermocouple peened into a rivet) within 6 minutes after quenching. This is in accordance with Manufacturing Process Specification 51.03F which requires a refrigerated temperature of less than + 10°F within 10 minutes after quenching.

The rivets were squeeze driven to 1.33-1.40 diameters with a cone point set or a universal set as noted in Tables I and II. Initial shank protrusion before upsetting was 1.05-1.16 diameters. The cone-shaped recess in the cone point set was .50 inches (max.) in diameter and .125 inches deep. Both upset and manufactured heads were inspected for rejectable cracks.

TEST PROCEDURE:

The testing of the specimens was accomplished in a 120,000 pound capacity Baldwin-Southwork Universal Test Machine. A mechanical arrangement of pivoted lever arms attached to the specimen and a dial gauge were used to measure specimen elongation over a 4 inch gauge length. A typical tensile test set-up for riveted lap-joints is shown in Figure 1.

The specimen was loaded to 50 pounds or 100 pounds in the tensile machine before attaching the strain measuring device. Progressively higher test loads were applied and then released to the 50 or 100 pound level where permanent deformation was measured. The rate of load application was approximately 1000 pounds per minute.

RESULTS AND DISCUSSION:

A. Shear strength of riveted joints

The test data for each individual riveted specimen of T.N. 57-922 are presented in Tables I and II. A summary of average values for T.N. 57-922 is given in Table V.

The test results include the ultimate and yield test load in pounds per fastener and the type of failure. The ultimate load was the maximum load per fastener carried by the test joint. The yield load of the test joints was determined as the load at which the following permanent set across the joint occurred:

(a) .005 inches for 5/32" and 3/16" diam. rivets.
(b) .00625 inches for 1/4" diam. rivets.

The average shear values for the riveted joints of T.N. 57-922 (100° -head 2024-T6 rivets) are compared with the ANC-5* allowable values for riveted joints incorporating 100° -head 2024-T31 rivets. (See Table V). This comparison reveals two conspicuously low yield values; namely, the average yield strengths of:

(a) 3/16" diam. 2024-T6 rivets in. .063" thk. 7075-T6 sheet and
(b) 1/4" diam. 2024-T6 rivets in .160" thk. 2024-T3 sheet

are 13 - 21% below the ANC-5 allowable. A visual examination of the failed specimens offered no explanation.

Bending of the lap joint and rotation of the fastener produced interaction loadings with a variety of types of failures in specimens with t/D ratios around 0.30. (See "Type of Failure" in Table I and II). It maybe noted from Table V that specimens for T.N. 57-922 with t/D ratios around .030 had ultimates about 25% greater than the ANC-5 allowable. The shear strengths of joints where there is no possibility of interaction loadings of the rivets (for example, the double shear test specimens of Report No. SG-1211) will vary from that of the above specimens.

B. Shear strength of undriven rivets

The results of shear tests perfomed on the undriven control rivets for T.N. 57-922 in the T-6 condition and in the T-31 condition are given in Table III and IV, respectively. Naturally aged T-31 wire has approximately the same ultimate shear strength as the artificially aged T-6 wire (within 3%). This suggests that 2024 rivets naturally aged at room temperature and then driven to 1.33-1.40 diameters might be equivalent in strength and cracking characteristics to the T-6 rivets of this test.

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* "Strength of Metal Aircraft Elements", ANC-5 Bulletin, p. 122-123 (March 1955)

C. Rejectable cracks in driven rivets

Table V shows the frequency of rejectable cracks in T-6 rivets driven to 1.33-1.40 diameters. Of the 354 rivets which were examined, only one shop head and four manufactured heads were rejectably cracked. The single rejectable shop head had been driven to 1.53 diameters. The large number of rejectable beveled heads in the 5/32 inch rivets can be attributed to the cone point set. Since the cone point was designed for 1/4 inch rivets, the operator had difficulty in centering the protruding shank of the 5/32 inch rivets in the deep cone-shaped recess of the cone point set.

NOTE:

The data from which this report was prepared are recorded in Materials & Processes Lab. Data Book No. 3011 and 879.

TABLE I
RESULTS OF TESTS ON RIVETED JOINTS INCORPORATING 100°-HEAD RIVETS(d)
IN COUNTERSUNK HOLES IN 2024-T3 CLAD ALUMINUM SHEET

Specimen Identif.	Squeeze Set	Rivet Diam., in.	Hole Diam., in.	Sheet Thk., in.	Specimen dimensions S	E	W (inches)	YIELD LOAD Pounds/ fastener	ULT. LOAD Pounds/ fastener	TYPE of FAILURE (c)
T3-050-1	Cone(a)	5/32	0.159	.050	5/8	5/16	1 3/16	---	662	2-b
-2	"				"	"	"	400	540	1-b
-3	"				"	"	"	357	495	2-a,2-h
-4	"				"	"	"	375	603	2-b,2-h
-5	"				"	"	"	---	610	2-b,2-h
-6	"				"	"	"	---	533	2-b,2-h
T3-050-1	Univ.(b)				5/8	5/16	1 1/16	---	650	1-d
-2	"				"	"	"	[illegible]	780	1-d
-3	"				"	"	"	---	787	2-b
-4	"				"	"	"	273	775	1-d
-5	"				"	"	"	---	808	2-d
-6	"				"	"	"	355	787	1-d
							Avg.	352	669	
T3-063-1	Cone(a)	5/32	0.159	.063	5/8	5/16	1 3/16	472	668	1-b
-2	"				"	"	"	---	690	"
-3	"				"	"	"	458	650	"
-4	"				"	"	"	405	628	"
-5	"				"	"	"	450	635	"
-6	"				"	"	"	505	637	"
							Avg.	458	650	

(a) Rivets squeezed with cone point set to 1.33-1.40 diameters.
(b) Rivets squeezed with universal set to 1.33-1.40 diameters.
(c) See page 13 for description of failure.
(d) 2024 rivets aged to T-6 condition before driving (3 3/4 hrs. at 398° F.)

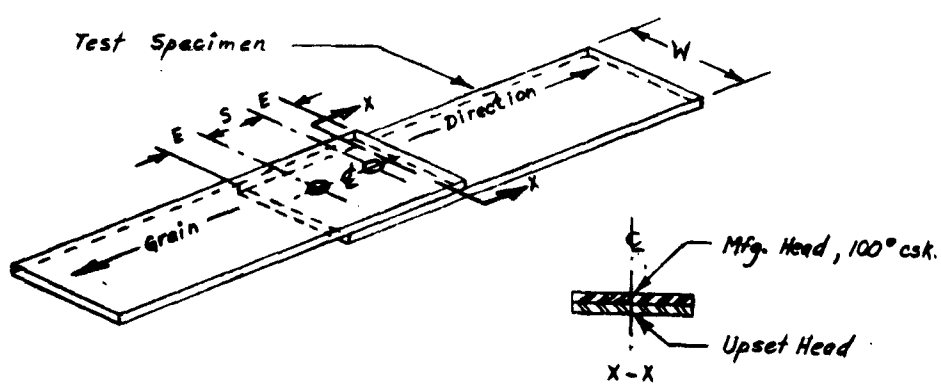


TABLE I (cont'd.)
RESULTS OF TESTS ON RIVETED JOINTS INCORPORATING 100°-HEAD RIVETS(d)
IN COUNTERSUNK HOLES IN 2024-T3 CLAD ALUMINUM SHEET

Specimen Identif.	Squeeze Set	Rivet Diam., in.	Hole Diam., in.	Sheet Thk., in.	Specimen dimensions(e) S	E	W (inches)	YIELD LOAD Pounds/ fastener	ULT. LOAD Pounds/ fastener	TYPE of FAILURE (c)
T3-071-1	Cone(a)	5/32	0.159	.071	5/8	5/16	1 3/16	565	700	1-a
-2	"				"	"	"	---	720	"
-3	"				"	"	"	525	680	"
-4	"				"	"	"	---	700	"
-5	"				"	"	"	---	752	"
-6	"				"	"	"	543	810	"
T3-081-1	Univ.(b)				"	"	1 1/16	520	875	"
-2	"				"	"	"	525	908	"
-3	"				"	"	"	482	877	"
-4	"				"	"	"	470	853	"
-5	"				"	"	"	490	847	"
-6	"				"	"	"	455	840	"
							Avg.	508	797	
T3-063-1	Cone(a)	3/16	0.191	.063	3/4	3/8	1 3/8	633	1245	1-b
-2	"				"	"	"	607	1320	"
-3	"				"	"	"	625	1252	"
-4	"				"	"	"	623	1270	"
-5	"				"	"	"	645	1288	"
-6	"				"	"	"	582	1138	"
							Avg.	619	1252	
T3-080-1	"	3/16	0.191	.080	3/4	3/8	1 3/8	---	1165	1-a
-2	"				"	"	"	---	1197	"
-3	"				"	"	"	827	1195	"
-4	"				"	"	"	910	1218	"
-5	"				"	"	"	845	1197	"
-6	"				"	"	"	818	1188	"
							Avg.	850	1193	
T3-100-1	"	3/16	0.191	.100	3/4	3/8	1 3/8	945	1208	1-a
-2	"				"	"	"	1038	1260	"
-3	"				"	"	"	920	1202	"
-4	"				"	"	"	1012	1288	"
-5	"				"	"	"	1002	1260	"
-6	"				"	"	"	1000	1242	"
							Avg.	986	1243	

(a) Rivets squeezed with cone point set to 1.33-1.40 diameters.
(b) Rivets squeezed with universal set to 1.33-1.40 diameters.
(c) See page 13 for description of failure.
(d) 2024 rivets aged to T-6 condition before driving (3 3/4 hrs. at 398° F.)
(e) See page 6 for specimen dimensions.

TABLE I (cont'd.)
RESULTS OF TESTS ON RIVETED JOINTS INCORPORATING 100°-HEAD RIVETS(d)
IN COUNTERSUNK HOLES IN 2024-T3 CLAD ALUMINUM SHEET

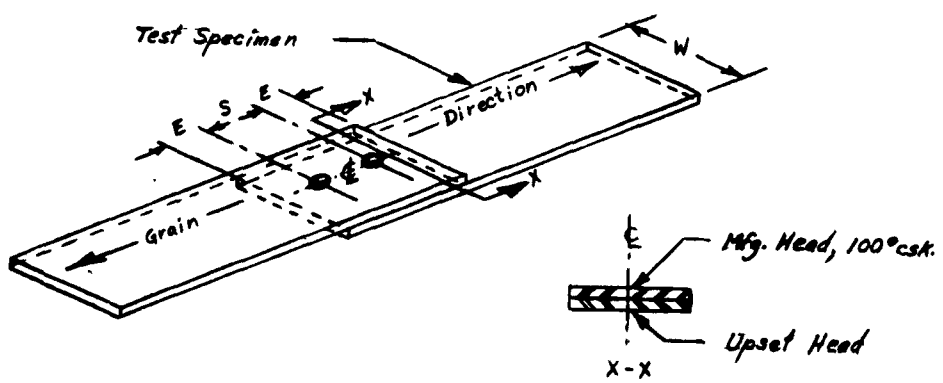
Specimen Identif.	Squeeze Set	Rivet Diam., in.	Hole Diam., in.	Sheet Thk., in.	Specimen dimensions(e) S	E	W	YIELD LOAD Pounds/ fastener	ULT. LOAD Pounds/ fastener	TYPE of FAILURE (c)
T3-125-2A	Cone(a)	3/16	0.191	.125	3/4	3/8	1 1/8	1008	1260	1-a
-2B	"				"	"	"	1075	1255	"
-2C	"				"	"	"	1012	1263	"
-2D	"				"	"	"	1113	1275	"
-2E	"				"	"	"	1072	1257	"
-2F	"				"	"	"	1085	1285	"
-1	"				"	"	"	960	1273	"
-2	"				"	"	"	795	1240	"
-3	"				"	"	"	925	1197	"
							Avg.	1005	1256	
T3-071-1	"	1/4	0.257	.071	1	1/2	1 7/8	920	2006	2-c,2-g
-2	"				"	"	"	847	2033	2-a,2-e
-3	"				"	"	"	878	2050	2-b,2-f
-4	"				"	"	"	908	2090	2-b,2-f
-5	"				"	"	"	902	2072	2-b,2-e
-6	"				"	"	"	987	2125	2-b,2-f
							Avg.	907	2062	
T3-090-1	"	1/4	0.257	.090	1	1/2	1 7/8	953	2365	1-d
-2	"				"	"	"	995	2360	"
-3	"				"	"	"	1182	2193	1-b
-4	"				"	"	"	1075	2300	1-d
-5	"				"	"	"	1088	2202	"
-6	"				"	"	"	1162	2250	"
							Avg.	1075	2278	
T3-125-1	"	1/4	0.257	.125	1	1/2	1 7/8	1415	2197	1-a
-2	"				"	"	"	---	2215	"
-3	"				"	"	"	1410	2130	"
-4	"				"	"	"	1417	2205	"
-5	"				"	"	"	1490	2220	"
-6	"				"	"	"	1463	2213	"
							Avg.	1439	2196	
T3-160-1	"	1/4	0.257	.160	1	1/2	1 7/8	1450	2315	1-a
-2	"				"	"	"	1552	2307	"
-3	"				"	"	"	1562	2305	"
-4	"				"	"	"	1345	2297	"
-5	"				"	"	"	1678	2328	"
-6	"				"	"	"	1330	2343	"
							Avg.	1469	2315	

(a) Rivets squeezed with cone point set to 1.33-1.40 diameters.
(c) See page 13 for description of failure.
(d) 2024 rivets aged to T-6 condition before driving (3 3/4 hrs. at 398°F.)
(e) See page 6 for specimen dimensions.

TABLE II
RESULTS OF TESTS ON RIVETED JOINTS INCORPORATING 100°-HEAD RIVETS(d)
IN COUNTERSUNK HOLES IN 2024-T6 CLAD ALUMINUM SHEET

Specimen Identif.	Squeeze Set	Rivet Diam. in.	Hole Diam., in.	Sheet Thk., in.	Specimen dimensions S	E	W inches	YIELD LOAD Pounds/ fastener	ULT. LOAD Pounds/ fastener	TYPE of FAILURE (c)
T6-050-1	Cone(a)	5/32	0.159	.050	5/8	5/16	1 1/8	483	690	1-b
-2	"				"	"	"	517	773	"
-3	"				"	"	"	508	667	"
-4	"				"	"	"	435	733	"
-5	"				"	"	"	492	750	"
-6	"				"	"	"	495	697	"
T6-051-1	Univ.(b)	5/32	0.159	.051	5/8	5/16	1 1/16	315	653	"
-2	"				"	"	"	373	785	"
-3	"				"	"	"	355	787	"
-4	"				"	"	"	300	783	"
-5	"				"	"	"	317	805	"
-6	"				"	"	"	313	767	"
							Avg.	408	741	
T6-063-1	Cone(a)	5/32	0.159	.063	5/8	5/16	1 1/8	430	740	1-b
-2	"				"	"	"	508	813	"
-3	"				"	"	"	512	845	"
-4	"				"	"	"	460	735	"
-5	"				"	"	"	593	867	"
-6	"				"	"	"	520	783	"
T6-063-1	Univ.(b)	5/32	0.159	.063	5/8	5/16	1 1/16	377	865	"
-2	"				"	"	"	325	875	"
-3	"				"	"	"	450	877	"
-4	"				"	"	"	400	808	"
-5	"				"	"	"	430	847	"
-6	"				"	"	"	388	790	"
							Avg.	450	820	

(a) Rivets squeezed with cone point set to 1.33-1.40 diameters.
(b) Rivets squeezed with universal set to 1.33-1.40 diameters.
(c) See page /3 for description of failure.
(d) 2024 rivets aged to T-6 condition before driving (3 3/4 hrs. at 398° F.)



FORM 1018-A

TABLE II (cont'd.)
RESULTS OF TESTS ON RIVETED JOINTS INCORPORATING 100°-HEAD RIVETS(d)
IN COUNTERSUNK HOLES IN 7075-T6 CLAD ALUMINUM SHEET

Specimen Identif.	Squeeze Set	Rivet Diam., in.	Hole Diam., in.	Sheet Thk., in.	Specimen dimensions(e) S	E	W (inches)	YIELD LOAD Pounds/ fastener	ULT. LOAD Pounds/ fastener	TYPE of FAILURE (c)
T6-071-1	Cone(a)	5/32	0.159	.071	5/8	5/16	1 1/8	560	830	1-a
-2	"				"	"	"	608	840	"
-3	"				"	"	"	590	843	"
-4	"				"	"	"	642	835	"
-5	"				"	"	"	520	792	"
-6	"				"	"	"	635	853	"
T6-071-1	"				5/8	5/16	1 1/16	570	840	"
-2	"				"	"	"	618	880	"
-3	"				"	"	"	697	877	"
-4	"				"	"	"	610	863	"
-5	"				"	"	"	650	880	"
-6	"				"	"	"	633	875	"
							Avg.	611	850	
T6-063-1	"	3/16	0.191	.063	3/4	3/8	1 1/16	478	998	1-b
-2	"				"	"	"	450	950	"
-3	"				"	"	"	430	775	"
-4	"				"	"	"	482	1050	"
-5	"				"	"	"	443	1150	"
-6	"				"	"	"	490	1050	"
T6-063-1	"				3/4	3/8	1 1/8	---	1075	"
-2	"				"	"	"	450	1087	"
-3	"				"	"	"	492	1088	"
-4	"				"	"	"	498	1172	"
-5	"				"	"	"	450	1015	"
-6	"				"	"	"	652	1225	1-c
							Avg.	463	1053	
T6-080-1	"	3/16	0.191	.080	3/4	3/8	1 3/8	845	1118	1-a
-2	"				"	"	"	840	1125	"
-3	"				"	"	"	900	1090	"
-4	"				"	"	"	820	1090	"
-5	"				"	"	"	805	1112	"
-6	"				"	"	"	900	1118	"
							Avg.	851	1109	

(a) Rivets squeezed with cone point set to 1.33-1.40 daimeters.
(c) See page 13 for description of failure.
(d) 2024 rivets aged to T-6 condition before driving (3 3/4 hrs. at 398° F.)
(e) See page 9 for specimen dimensions.

TABLE II (cont'd.)
RESULTS OF TEST ON RIVETED JOINTS INCORPORATING 100°-HEAD RIVET(d)
IN COUNTERSUNK HOLES IN 7075-T6 CLAD ALUMINUM SHEET

Specimen Identif.	Squeeze Set	Rivet Diam. in.	Hole Diam. in.	Sheet Thk., in.	Specimen dimensions(e) S	E	W (inches)	YIELD LOAD Pounds/ fastener	ULT. LOAD Pounds/ fastener	TYPE of FAILURE (c)
T6-100-1	Cone(a)	3/16	0.191	.100	3/4	3/8	1 3/8	968	1138	1-a
-2	"				"	"	"	980	1162	"
-3	"				"	"	"	1067	1210	"
-4	"				"	"	"	983	1120	"
-5	"				"	"	"	1000	1180	"
-6	"				"	"	"	990	1160	"
							Avg.	998	1161	
T6-125-2A	"	3/16	0.191	.125	3/4	3/8	1 1/16	1110	1260	1-a
-2B	"				"	"	"	1078	1283	"
-2C	"				"	"	"	1035	1275	"
-2D	"				"	"	"	1067	1260	"
-2E	"				"	"	"	1060	1257	"
-2F	"				"	"	"	1045	1248	"
-1	"				"	"	1 1/8	1020	1215	"
-2	"				"	"	"	798	1250	"
-5	"				"	"	"	942	1155	"
							Avg.	1017	1244	
T6-072-1	"	1/4	0.257	.072	1	1/2	1 7/8	908	1850	2-a
-2	"				"	"	"	900	2220	2-b
-3	"				"	"	"	885	2030	2-b
-4	"				"	"	"	----	2078	1-d
-5	"				"	"	"	897	1707	1-b
-6	"				"	"	"	895	2243	1-d
							Avg.	897	2021	
T6-090-1	"	1/4	0.257	.090	1	1/2	1 7/8	940	2135	1-b
-2	"				"	"	"	1133	1953	"
-3	"				"	"	"	1025	1997	"
-4	"				"	"	"	937	2035	"
-5	"				"	"	"	---	2060	"
-6	"				"	"	"	1080	1893	"
							Avg.	1023	2012	

(a) Rivets squeezed with cone point set to 1.33-1.40 diameters.
(c) See page 13 for description of failure.
(d) 2024 rivets aged to T-6 condition before driving (3 3/4 hrs. at 396° F.)
(e) See page 9 for specimen dimensions.

TABLE II (cont'd.)
RESULTS OF TESTS ON RIVETED JOINTS INCORPORATING 100°-HEAD RIVETS(d)
IN COUNTERSUNK HOLES IN 7075-T6 CLAD ALUMINUM SHEET

Specimen Identif.	Squeeze Set	Rivet Diam., in.	Hole Diam., in.	Sheet Thk., in.	Specimen Dimensions(e) S	E	W (inches)	YIELD LOAD Pounds/ fastener	ULT. LOAD Pounds/ fastener	TYPE of FAILURE (c)
T6-125-1	Cone(a)	1/4	0.257	.125	1	1/2	1 7/8	1445	---	1-a
-2	"				"	"	"	---	2250	"
-3	"				"	"	"	1420	2155	"
-4	"				"	"	"	1475	2223	"
-5	"				"	"	"	1470	2230	"
-6	"				"	"	"	1593	2202	"
							Avg.	1480	2212	
T6-160-1	"	1/4	0.257	.160	1	1/2	1 7/8	1740	2288	1-a
-2	"				"	"	"	1600	2265	"
-3	"				"	"	"	1515	2232	"
-4	"				"	"	"	1675	2240	"
-5	"				"	"	"	1753	2255	"
-6	"				"	"	"	1737	2303	"
							Avg.	1670	2264	

(a) Rivets squeezed with cone point set to 1.33-1.40 diameters.
(c) See page 13 for description of failure.
(d) 2024 rivets aged to T-6 condition before driving (3 3/34 hrs. at 398° F.)
(e) See page 9 for specimen dimensions.

TYPE OF FAILURE

The types of failures, referred to in Tables I and II, are as follows:

1. Shear failure of both fasteners thru cross-section of shank

   a. With no noticeable deformation of the hole.

   b. With noticeable elongation of the hole where the rivet flattened the knife edge created by countersinking.

   c. With very slight elongation of hole and only slight flattening of the knife edge created by countersinking.

   d. With noticeable elongation of the hole where the rivet flattened the knife edge created by countersinking which allowed some rotation of the fastener and subsequent "dimpling" (slight) of the non-countersunk sheet.

2. Initial sheet bearing failure followed by:

   a. Rotation of rivets and bending of the joint causing 100°-head to chip and shear along the axis of the rivet.

   b. Rotation of rivets and bending of the joint with shear thru the shank of one rivet and shear thru the 100°-head of the other rivet (along the axis of the rivet).

   c. Rotation of rivets and bending of the joint causing severe elongation of one countersunk hole and shear out of the countersunk sheet thru the edge margin of the other hole (fastener pulls through sheet chipping out pieces of the 100°-head).

   d. Rotation of rivets and bending of the joint causing 100°-head to curl up & chip & pull thru sheet without tearing sheet.

   e. Shear out of the countersunk sheet through edge margin.

   f. Tearing of the sheet around countersunk holes.

   g. Tearing of sheet around non-countersunk holes.

   h. Folding under and tearing out of the knife edge created by countersinking.

TABLE VII
MECHANICAL PROPERTIES OF UNDRIVEN 2024-T6[a] RIVETS

Identif.	RIVET DIAM. Nominal in.	RIVET DIAM. Measured in.	C.S.A.[d] in.^{2}	ULTIMATE Load[b] pounds	ULTIMATE Strength[c] psi.	Average Strength psi.	Guaranteed Minimum psi.
B1-Dec.16	5/32	.156	.01910	1780	46,600		
TB-Dec.18	"	"	"	1720	45,050		
"	"	"	"	1720	45,050		
"	"	"	"	1750	45,800		
"	"	"	"	1760	46,100		
"	"	"	"	1730	45,250		
BB-Dec.18	"	"	"	1735	45,400		
"	"	"	"	1730	45,250	45,550	44,000
B2-Dec.16	3/16	.186	.02716	2475	45,650		
TB-Dec.17	"	"	"	2422	44,600		
"	"	"	"	2440	44,950		
"	"	"	"	2425	44,650		
"	"	"	"	2457	45,300		
BB-Dec.17	"	"	"	2488	45,850		
"	"	"	"	2500	46,100		
"	"	"	"	2465	45,400		
"	"	"	"	2487	45,850		
"	"	"	"	2490	45,900		
TB-Dec.18	"	"	"	2580	47,550		
"	"	"	"	2610	48,150		
"	"	"	"	2580	47,550		
BB-Dec.18	"	"	"	2550	47,000		
"	"	"	"	2600	47,800	46,100	44,000
B1-Dec.16	1/4	.250	.04906	4460	45,500		
B2-Dec.16	"	"	"	4380	44,700		
B3-Dec.16	"	"	"	4500	45,900		
TB-Dec.17	"	"	"	4410	45,000		
"	"	"	"	4445	45,300		
"	"	"	"	4460	45,500		
BB-Dec.17	"	"	"	4520	46,150		
"	"	"	"	4545	46,300		
"	"	"	"	4515	46,000		
TB-Dec.18	"	"	"	4450	45,350		
"	"	"	"	4610	46,950		
"	"	"	"	4680	47,700		
BB-Dec.18	"	"	"	4730	48,200		
"	"	"	"	4745	48,400		
"	"	"	"	4690	47,800	46,300	44,000

(a) Quenched and aged at 398° F. for 3 3/4 hours.
(b) Ultimate load for double-shear on one rivet.
(c) Ultimate strength in single-shear.
(d) Cross-sectional area of rivet.

TABLE IX
MECHANICAL PROPERTIES OF UNDRIVEN 2024-T31[a] RIVETS

Identif.	RIVET DIAM. Nominal in.	RIVET DIAM. Measured in.	C.S.A.[d] in.^{2}	ULTIMATE Load[b] pounds	ULTIMATE Strength[c] psi.	Average Strength psi.	Guaranteed Minimum psi.
E1-Jan.29	3/16	.1873	.02755	2475	44,915		
"	"	"	"	2500	45,365		
"	"	"	"	2500	45,365		
"	"	"	"	2400	43,550		
"	"	"	"	2450	44,460		
"	"	"	"	2400	43,550		
E2-Feb.27	"	"	"	2460	44,640		
"	"	"	"	2440	44,280		
"	"	"	"	2460	44,640		
"	"	"	"	2520	45,730		
"	"	"	"	2500	45,365		
E3-Feb.3	"	"	"	2520	45,730		
"	"	"	"	2500	45,365		
E5-Feb.3	"	"	"	2520	45,730		
"	"	"	"	2480	45,005		
"	"	"	"	2480	45,005		
E7-Jan.28	"	"	"	2460	44,640		
"	"	"	"	2400	43,550		
"	"	"	"	2400	43,550	44,750	43,000
E1-Jan.29	1/4	.2502	.04916	4475	45,510		
"	"	"	"	4475	45,510		
"	"	"	"	4520	45,965		
E3-Feb.3	"	"	"	4520	45,965		
E4-Feb.19	"	"	"	4540	46,170		
"	"	"	"	4560	46,370		
"	"	"	"	4580	46,575		
E5-Feb.3	"	"	"	4560	46,370		
"	"	"	"	4540	46,170		
"	"	"	"	4520	45,965	46,060	43,000

(a) Quenched & frozen to -100° F.; then naturally aged at room temperature for two weeks.
(b) Ultimate load for double-shear on one rivet.
(c) Ultimate strength in single-shear.
(d) Cross-sectional area of rivet.

FORM 1512-A

TABLE V

A COMPARISON OF T.N. 57-922 RESULTS WITH ANC-5 "ALLOWABLE" SHEAR LOADS*
(100°-HEAD 2024 RIVETS IN CSK. HOLES IN ALCLAD)

Rivet Material:			2024-T6(a) (Test Data)		2024-T31(b) (ANC-5 Values)*		Examination of driven 2024-T6(b) rivets for cracks (prior to shear test)					
Rivet Diam., in.	Sheet Thk., in.	Sheet Mat'l.	AVERAGE ULT. LOAD ÷ 1.15	AVERAGE YIELD LOAD #/fastener	AVERAGE ULT. LOAD ÷ 1.15	AVERAGE YIELD LOAD #/fastener	Squeeze Set	Upset Diam., in.	Total No. of Rivets Examined	Rejectable Rivets Cracked	Rejectable Rivets Beveled	REMARKS (c)
5/32	.050	2024-T3	499	377	---	---	Cone	.216-.224	12	0	0	2-a
"	"	"	664	314	---	---	Univ.	.203-.208	12	0	0	2-a
"	"	7075-T6	624	488	---	---	Cone	.217-.223	12	0	0	2-a
"	"	"	883	329	---	---	Univ.	.203-.208	12	0	0	2-a
"	.063	2024-T3	565	458	---	---	Cone	.209-.220	12	0	6	1
"	"	7075-T6	693	504	---	---	"	.196-.215	12	1 mfg.	1	1,4
"	"	"	733	395	---	---	Univ.	.206-.211	12	0	0	1
"	.071	2024-T3	632	544	---	---	Cone	.204-.212	12	0	2	2-a,3
"	"	"	753	490	---	---	Univ.	.200-.219	12	0	0	2-a
"	"	7075-T6	739	611	---	---	Cone	.200-.214	24	0	0	2-a
3/16	.063	2024-T3	1089	619	886*	614*	Cone	.250-.255	12	0	0	1
"	"	7075-T6	916	483	"	"	"	.237-.254	24	0	0	2-a
"	.090	2024-T3	1057	850	992*	761*	"	.260-.264	12	0	0	2-b
"	"	7075-T6	964	851	"	"	"	.251-.255	12	0	0	2-b
"	.100	2024-T3	1061	986	1073*	913	"	.251-.260-	12	1 mfg.	0	2-b,4
"	"	7075-T6	1010	998	"	"	"	.250-.288	12	1 shop	0	2-b,5
"	.125	2024-T3	1092	1005	1131*	1021*	"	.248-.261	18	2 mfg.	0	2-a,4
"	"	7075-T6	1062	1017	"	"	"	.248-.267	24	0	0	2-b
1/4	.071	2024-T3	1793	907	1424*	902*	Cone	.333-.337	12	0	0	1
"	"	7075-T6	1757	897	"	"	"	.331-.336	12	0	0	1
"	.090	2024-T3	1961	1075	1647*	1053*	"	- -	12	0	0	1
"	"	7075-T6	1750	1023	"	"	"	.339-.360	12	0	0	2-b
"	.125	2024-T3	1910	1439	1877*	1357*	"	.331-.337	12	0	0	1
"	"	7075-T6	1924	1480	"	"	"	.330-.343	12	0	0	2-b
"	.160	2024-T3	2013	1469	2000*	1694*	"	.334-.345	12	0	0	1
"	"	7075-T6	1969	1670	"	"	"	.337-.343	12	0	0	1

(a) 2024 rivets aged to T-6 condition before driving (3 3/4 hrs. at 398° F.)
(b) "Ice box" rivets maintained in solution treated condition until driving.
(c) See page 17 for explanation of REMARKS.
(d) Rejectable according to standards established inMPS-46.05D.

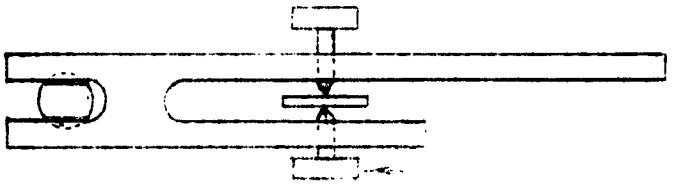
* Allowable single-shear strength from "Strength of Metal Aircraft Elements" ANC-5 Bulletin, p. 86 (JUNE 1951)

REMARKS

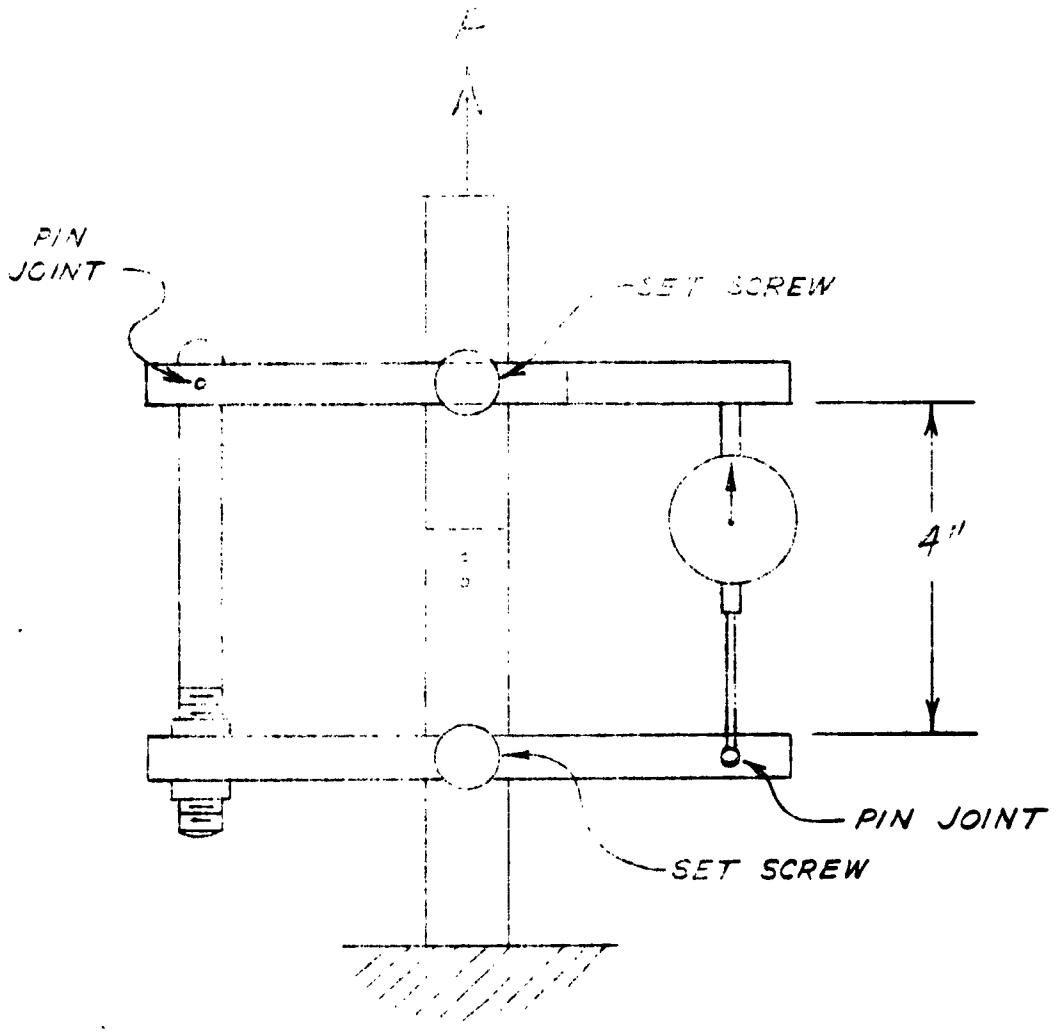
The "Remarks" referred to in Table V are as follows:

1. No cracks.
2. Non-rejectable radial cracks in shop heads.
   a. Very slight hair-line cracks.
   b. Greater than 2-a.
3. Non-rejectable chipped shop head.
4. Rejectable cracked manufactured heads.
5. Rejectable radial cracks in shop head due to upsetting to greater than 1.40 diameters where

D_0	$D_{1.40}$
.1563	.2188
.1875	.2625
.250	.350



SET SCREW



SKETCH SHOWING TYPICAL TENSILE TEST SET-UP.

FIGURE 1.

CONVAIR

A DIVISION OF GENERAL DYNAMICS CORPORATION

SAN DIEGO

REPORT 57-922, App.1

DATE 28 January 1959

MODEL _____

TITLE

TEST OF ARTIFICIALLY AGED 2024 ALUMINUM ALLOY RIVETS

PREPARED BY Roy A. Miller
Roy A. Miller

GROUP Engineering Materials

REFERENCE _____

CHECKED BY _____

APPROVED BY W. H. Steurer
W. H. Steurer

NO. OF PAGES _____

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REVISIONS

NO.	DATE	BY	CHANGE	PAGES AFFECTED

FORM 1612A-4

TEST OF ARTIFICIALLY AGED 2024 ALUMINUM ALLOY RIVETS

Object:

The object of this appendix is to present and discuss the tests conducted on aged 2024 rivets between the ones presented in Reports No. 56-191 and 57-922.

In each instance, the test specimen consisted of a lap joint of two strips of aluminum alloy sheet, nearly always of clad 7075-T6 sheet, with two centered tandem rivets spaced at four rivet diameters, and with two diameters edge distance. Some of the rivets were gun driven and some were squeezed. Some had universal heads and some had 100° flush heads. The effects of initial shank protrusion, driven head diameters and of variations in the overaging cycle were also checked by these lap joint tests. The results of all these tests are presented in Tables 1 to 14 inclusive, of this appendix.

A great many simple shear tests were also conducted, primarily to check the effect of variations in the temperature and time of the aging cycle on the shear strength. But these data have not been assembled for presentation in this appendix.

The contributions of these various effects in causing rejectable cracks in the rivets may be noted by means of the following percentages:

1. Considering a summation of all the rivets tested, 8.375% had one or more rejectable cracks.

2. Considering the method of driving, we find that 9.16% of the squeeze driven rivets and 5.72% of the gun driven rivets had rejectable cracks.

3. Considering the effect of head size we find that driving them to 1 1/3 shank diameters caused 1.93% and that driving them to 1 1/2 shank diamters caused 15.2% to have rejectable cracks.

4. Considering the effect of the amount of initial shank protrusion we find that a protrusion of 1 - 1 1/3 shank diameters resulted in 5.19% of rejectable cracked rivets, while one of 1 1/3 to 1 1/2 diameters resulted in 15.83%.

5. Considering the effect of the rivet shank diameter, we find the following numbers of rejectable cracked rivets in terms of percent:

1/8" rivets — 5.45%
5/32" rivets — 6.84%
3/16" rivets — 9.25%
1/4" rivets — 5.74%

In Table 14 are presented the test results for each aging cycle investigated. These data include not only a summary of the percentages of rejectable cracked rivets, but in each case, includes also the percentage of specimens when average test strengths did not equal the design strengths listed in ANC-5. The best one, if you eliminate the cycles for which less than 10 tests were made, would be to age at 395°F. for 4 hours. But when the necessity of permitting some tolerance in heat treating, as ± 5°F. in temperature and ± 10' in time, is considered, it is obvious that the rejection rate will be so high that the overaged 2024 rivet, as a substitute for the Ice Boxed 2024 rivets, cannot be tolerated in our Shops.

TABLE I

2024 RIVETS IN LAP JOINTS OF CLAD 7075-T6 SHEET

Rivet Size	Aging Temp. °F	Aging Time	Type Head	Shank Protrusion	Diam. of Driven Head	How Driven	Sheet Thickness	Number of Tests	Ultimate Average Shear Stress	No. of Rejectable Cracked Rivets
1/4	395	4 hrs.	Universal	1 D.	1 1/3 D	Squeeze	.090	5	49350	0
"	"	5	"	"	"	"	"	2	46550	0
"	"	6	"	"	"	"	"	2	45900	0
"	405	4	"	"	"	"	"	2	46750	0
"	"	4 1/4	"	"	"	"	"	3	46575	0
"	"	5	"	"	"	"	"	2	43100	0
"	"	6	"	"	"	"	"	2	44250	0
"	415	3	"	"	"	"	"	2	47850	0
"	"	4	"	"	"	"	"	2	44850	0
"	"	4 1/2	"	"	"	"	"	5	43720	0
"	"	5	"	"	"	"	"	2	47350	0
"	425	3	"	"	"	"	"	2	44100	0
"	"	4	"	"	"	"	"	2	44600	0
"	"	5	"	"	"	"	"	2	40100	0
"	395	5	"	1 1/3 D.	1 1/2 D.	"	"	2	48250	1
"	"	6	"	"	"	"	"	2	48250	3
"	405	5	"	"	"	"	"	2	46000	0
"	"	6	"	"	"	"	"	2	45950	1
"	415	4	"	"	"	"	"	2	44450	0
"	"	5	"	"	"	"	"	2	44300	3
"	425	4	"	"	"	"	"	2	41300	2
"	"	5	"	"	"	"	"	2	40200	0
"	415	4 1/2	"	1 D	1 1/2 D	"	"	5	41720	0
3/16	"	"	"	"	1 1/3 D	"	.072	5	40800	0
"	"	"	"	"	1 1/2 D	"	"	5	41260	9

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FORM

TABLE 2

UNIVERSAL HEAD RIVETS IN LAP JOINTS OF CLAD 7075-T6 SHEET

Rivet Size	Aging Temp. °F	Aging Time-Hrs	Shank Protrusion	Diam. of Driven Head	How Driven	Sheet Thickness	Low Tolerance Holes			High Tolerance Holes		
							Number of Tests	Average Shear Stress	Rejectable Cracked Rivets	Number of Tests	Average Shear Stress	Rejectable Cracked Rivets
1/8	Ice Boxed		1D	1.36 D.	Squeezed	.051	10	45080	0	8	48850	0
"	395	4	"	1.40 D	"	"	10	48800	0	10	53380	0
"	405	4¼	"	1.40 D	"	"	10	45220	0	10	45960	0
"	Ice Boxed		1⅓ D	1.32 D	"	"	6	43467	0	10	47840	0
"	395	4	"	1.44 D	"	"	8	50875	0	10	52700	0
"	405	4¼	"	1.44 D	"	"	10	43880	0	10	46040	0
"	Ice Boxed		1D.	1.33 D	Gun	"	10	42260	0	10	47380	0
"	395	4	"	1.48 D	"	"	10	49700	0	10	51940	0
"	405	4¼	"	1.44 D	"	"	10	44580	0	10	45500	0
"	Ice Boxed		1⅓ D	1.38 D	"	"	10	43680	0	10	47520	0
"	395	4	"	1.52 D	"	"	10	49680	0	10	51580	0
"	405	4¼	"	1.50 D	"	"	10	44260	0	10	45440	0
5/32	Ice Boxed		1D	1.345 D	Squeezed	.063	10	43080	0	10	45720	0
"	395	4	"	1.345 D	"	"	10	47120	0	10	51300	0
"	405	4¼	"	1.295 D	"	"	10	44540	0	8	46075	0
"	Ice Boxed		1⅓ D	1.41 D	"	"	10	44180	2	8	46475	4
"	395	4	"	1.38 D	"	"	10	45940	5	8	43975	1
"	405	4¼	"	1.345 D	"	"	10	42220	1	8	44825	0
"	Ice Boxed		1D	1.345 D	Gun	"	10	43200	0	10	47900	0
"	395	4	"	1.36 D	"	"	10	46280	0	10	51540	0
"	405	4¼	"	1.345 D	"	"	10	41540	0	10	43520	0
"	Ice Boxed		1⅓ D	1.36 D	"	"	10	45840	0	10	47960	1
"	395	4	"	1.41 D	"	"	10	47560	5	10	46830	1
"	405	4¼	"	1.41 D	"	"	10	42680	3	10	45480	2

Table 2

ST-922 Appl

TABLE 3

UNIVERSAL HEAD RIVETS IN LAP JOINTS OF CLAD 7075-T6 SHEET

Rivet Size	Aging Temp. °F	Aging Time - Hrs.	Shank Protrusion	Diam. of Driven Head	How Driven	Sheet Thickness	Low Tolerance Holes: Number of Tests	Low Tolerance Holes: Average Shear Stress	Low Tolerance Holes: Rejectable Cracked Rivets	High Tolerance Holes: Number of Tests	High Tolerance Holes: Average Shear Stress	High Tolerance Holes: Rejectable Cracked Rivets
3/16	Ice Boxed		1 D.	1.36 D	Squeezed	.071	10	45020	0	10	45360	0
"	395	4	"	1.43 D	"	"	10	47320	0	10	52920	0
"	405	4 1/4	"	1.36 D	"	"	10	43260	0	10	47460	0
"	Ice Boxed		1 1/3 D	1.36 D	"	"	10	42660	0	8	46525	0
"	395	4	"	1.35 D	"	"	10	47600	0	10	47600	0
"	405	4 1/4	"	1.37 D	"	"	10	43460	0	10	43630	4
"	Ice Boxed		1 D	1.37 D	Gun	"	10	45140	0	10	46900	0
"	395	4	"	1.33 D	"	"	10	45320	0	10	45120	0
"	405	4 1/4	"	1.49 D	"	"	10	41760	0	10	47260	0
"	Ice Boxed		1 1/3 D	1.51 D	"	"	10	44220	0	10	45360	0
"	395	4	"	1.32 D	"	"	10	45560	0	10	46500	0
"	405	4 1/4	"	1.45 D	"	"	10	42860	0	10	45020	0
1/4	Ice Boxed		1 D	1.33 D	Squeezed	.090	10	43820	0	10	46160	0
"	395	4	"	1.34 D	"	"	10	49860	1	10	47000	0
"	405	4 1/4	"	1.34 D	"	"	10	44960	1	10	46700	0
"	Ice Boxed		1 1/3 D	1.40 D	"	"	10	44580	0	10	47860	0
"	395	4	"	1.39 D	"	"	10	49040	2	10	48600	5
"	405	4 1/4	"	1.34 D	"	"	10	46680	3	10	48540	6
"	Ice Boxed		1 D	1.40 D	Gun	"	10	45850	0	10	46600	0
"	395	4	"	1.38 D	"	"	10	47920	0	10	52080	1
"	405	4 1/4	"	1.35 D	"	"	10	44980	0	10	47380	0
"	Ice Boxed		1 1/3 D	1.41 D	"	"	10	44300	0	10	48300	0
"	395	4	"	1.42 D	"	"	10	46920	3	10	50840	6
"	405	4 1/4	"	1.38 D	"	"	10	46760	0	10	48960	1

TABLE 4

MACHINE COUNTERSUNK RIVETS IN LAP JOINTS OF CLAD 7075-T6 SHEET

Rivet Size	Aging Temp. °F	Aging Time Hrs.	Diam. of Driven Head	How Driven	Sheet Thickness	Number of Tests	Average Test Ultimate Lbs.	Average Test Yield Lbs.	Test Design Ult.	ANC-5 Values Design Ult.	ANC-5 Values Design Yield	Rejectable Cracked Rivets
3/16	Ice Boxed		1 1/3	Squeezed	.072	6	1145	775	995	1424	902	0
"	"	"	1 1/3	Gun	"	6	1154	742	1004	"	"	0
"	"	"	1 1/2	Squeezed	"	6	1143	796	994	"	"	6
"	"	"	1 1/2	Gun	"	6	1184	885	1030	"	"	0
"	395	3 3/4	1 1/3	Squeezed	"	6	1172	739	1020	"	"	0
"	"	"	1 1/3	Gun	"	6	1235	727	1073	"	"	0
"	"	"	1 1/2	Squeezed	"	5	1187	798	1032	"	"	10
"	"	"	1 1/2	Gun	"	6	1202	870	1045	"	"	9
"	400	4 3/4	1 1/3	Squeezed	"	6	1147	727	997	"	"	0
"	"	"	1 1/3	Gun	"	6	1202	619	1045	"	"	0
"	"	"	1 1/2	Squeezed	"	6	1151	825	1000	"	"	10
"	"	"	1 1/2	Gun	"	6	1202	891	1045	"	"	12
"	405	4 1/4	1 1/3	Squeezed	"	3	1106	598	961	"	"	0
"	"	"	1 1/3	Gun	"	3	1092	736	949	"	"	0
"	"	"	1 1/3	Squeezed	"	6	1063	562	925	"	"	0
"	"	"	1 1/3	Gun	"	6	1070	726	930	"	"	0
"	"	"	1 1/2	Squeezed	"	6	1092	703	949	"	"	7
"	"	"	1 1/2	Gun	"	6	1088	789	946	"	"	6
5/32	Ice Boxed		1 1/3	Squeezed	.063	6	791	617	688			0
"	"	"	1 1/3	Gun	"	6	859	687	747			0
"	"	"	1 1/2	Squeezed	"	5	842	697.5	732			0
"	"	"	1 1/2	Gun	"	5	881	759	766			0
"	405	5	1 1/3	Squeezed	"	6	812	541	706			0
"	"	"	1 1/3	Gun	"	6	827	682.5	719			0
"	"	"	1 1/2	Squeezed	"	6	823	651	716			8
"	"	"	1 1/2	Gun	"	6	886	702	770			5

TABLE 5

MACHINE COUNTERSUNK RIVETS IN LAP JOINTS OF CLAD 7075-T6 SHEET

Rivet Size	Aging Temp. °F	Aging Time-Hrs	Diam. of Driven Head	How Driven	Sheet Thickness	Number of Tests	Average Test Ultimate Lbs	Average Test Yield Lbs	Test Design Ult.	ANC-5 Values Design Ult.	ANC-5 Values Design Yield	Rejectable Cracked Rivets
1/4	Ice Boxed		1 1/3	Squeeze	.090	6	1982	1159	1723	1647	1053	0
"	"	"	1 1/3	Gun	"	6	2212	1255	1923	"	"	0
"	"	"	1 1/2	Squeeze	"	6	2110	1239	1835	"	"	0
"	"	"	1 1/2	Gun	"	6	2260	1463	1965	"	"	0
"	395	4	1 1/3	Squeeze	"	3	2099	833	1826	"	"	0
"	"	"	1 1/3	Gun	"	3	2045	844	1778	"	"	0
"	"	"	1 1/2	Squeeze	"	3	2099	1090	1826	"	"	6
"	"	"	1 1/2	Gun	"	3	2132	1383	1853	"	"	5
"	405	4 1/4	1 1/3	Squeeze	"	3	1928	756	1677	"	"	0
"	"	"	1 1/3	Gun	"	6	1853	833	1612	"	"	0
"	"	"	1 1/2	Squeeze	"	5	1860	1004	1617	"	"	0
"	"	"	1 1/2	Gun	"	6	2041	1159	1775	"	"	0
1/8	Ice Boxed		1 1/3	Squeeze	.050	6	504	393	439			0
"	"	"	1 1/3	Gun	"	6	547	437.5	476			0
"	"	"	1 1/2	Squeeze	"	5	536	444	466			0
"	"	"	1 1/2	Gun	"	6	547.5	483	476			0
"	395	4	1 1/3	Squeeze	"	6	591	398	514			0
"	"	"	1 1/3	Gun	"	6	586	462.5	510			0
"	"	"	1 1/2	Squeeze	"	6	587	440	511			5
"	"	"	1 1/2	Gun	"	6	595	498	517			6
"	"	"	1 1/3	Squeeze	"	6	575	401	500			0
"	"	"	1 1/3	Gun	"	6	575	406	500			0
"	"	"	1 1/2	Squeeze	"	6	600	436	522			11
"	"	"	1 1/2	Gun	"	6	586	501	510			11

TABLE 6
2024 RIVETS IN LAP JOINTS OF CLAD 7075-T6 SHEET

Rivet Size	Aging Temp. °F	Aging Time-Hrs.	How Driven	Sheet Thickness	Number of Tests	Average Test Ultimate Lbs	Average Test Yield Lbs.	Test Design Ult.	ANC-5 Values Design Ult.	ANC-5 Values Design Yield
Protruding Head Rivets:										
1/8	Ice Boxed		Squeezed	.050	3	572	503	497	532	
3/16	"	"	"	.072	13	1245	1053	1082	1175	
1/4	"	"	"	.090	11	2268	1880	1972	2126	
1/8	405	4 1/4	"	.050	10	540	501	470	532	
3/16	395	4	"	.072	7	1384	1075	1203	1175	
"	405	4 1/4	"	"	5	1287	1056	1118	"	
"	405	4 1/2	"	"	10	1247	1082	1085	"	
1/4	395	4	"	.090	9	2367	1943	2056	2126	
"	405	4 1/4	"	"	8	2301	1871	2000	"	
"	405	4 1/2	"	"	10	2320	2067	2017	"	
Machine Countersunk Rivets:										
3/16	Ice Boxed		Squeezed	.072	7	1112	573	860	942	669
1/4	"	"	"	.090	4	2170	1336	1887	1647	1053
3/16	405	5 1/4	"	.063	6	919	517	775	886	614
"	395	4	"	.072	4	1176	769	1022	942	669
"	405	4 1/4	"	"	5	1109	616	924	942	669
"	405	5 1/4	"	.090	6	1027	766	893	1035	842
1/4	395	4	"	"	3	2075	1117	1675	1647	1053
"	405	4 1/4	"	"	6	1628	1003	1415	1647	1053

TABLE 7

2024 RIVETS IN LAP JOINTS OF CLAD ALUMINUM ALLOY SHEET

Rivet Size	Aging Temp. °F	Aging Time-Hrs	How Driven	Sheet Thickness	Number of Tests	Average Test Ultimate Lbs.	Average Test Yield Lbs.	Test Design Ult.	ANC-5 Values Design Ult.	ANC-5 Values Design Yield
Protruding Head Rivets in 7075-T6 Sheet:										
1/8	Ice Box		Squeezed	.050	3	572	503	497	532	
"	405	4 1/4	"	"	10	540	500	470	532	
3/16	Ice Box		"	.071	5	1244	1098	1082	1175	
"	405	4 1/2	"	"	10	1247	1082	1084	1175	
1/4	Ice Box		"	.090	3	2240	1931	1948	2126	
"	405	4 1/2	"	"	10	2320	2067	2017	2126	
Machine Countersunk Rivets in 7075-T6 Sheet:										
5/32	Ice Box		Squeezed	.040	6	761	296	444		
"	405	5	"	.040	6	680	263	394		
"	Ice Box		"	.050	6	786	352	528		
"	405	5	"	.050	6	664	279	418		
"	Ice Box		"	071	6	821	548	714		
"	405	5	"	.063	6	760	451	661		
3/16	405	5 1/4	"	.040	6	820	294	441	555	362
"	"	"	"	.063	6	919	517	775	886	614
"	"	"	"	.090	6	1027	766	893	1035	842
1/4	405	4 1/4	"	.063	6	1729	596	894	1290	811
"	"	"	"	.090	6	1628	1003	1415	1647	1053
"	"	"	"	.125	6	2046	1267	1779	1877	1357
Dimpled Rivets in 2024-T3 Sheet:										
1/8	Ice Box		Squeezed	.032	3	544	366	473		
"	405	4 1/4	"	"	6	473	331	412		
5/32	Ice Box		"	"	4	668	512	581		
"	405	5	"	"	6	672	555	584		

TABLE 8

2024 RIVETS IN LAP JOINTS OF CLAD 7075-T6 SHEET

Rivet Size	Aging Temp. °F	Aging Time-Hrs	Diam. of Driven Head	Protrusion in Shank Diams.	Sheet Thickness	Number of Tests	Average Test Ultimate Lbs.	Average Test Yield Lbs.	Test Design Ult. Lbs	ANC-5 Values Ult. in Lbs	ANC-5 Values Yield in Lbs.	Rejectable Cracked Rivets
Protruding Head Rivets:												
3/16	Ice	Boxed	1.50	1/3	.040	4	1172		1172	1142		0
"	400	3¾	"	"	"	9	1244	1123	1244	"		0
"	Ice	Boxed	"	"	.063	9	1249	1185	1249	1175		5
"	400	3¾	"	"	"	4	1203.5		1203	"		6
"	Ice	Boxed	"	"	.090	9	1316.5	1201	1316	"		14
"	400	3¾	"	"	"	9	1334	1268.5	1334	"		7
1/4	Ice	Boxed	"	"	.063	5	2079.5	1772.5	2079	2050		0
"	400	3¾	"	"	"	4	2283		2283	"		0
"	Ice	Boxed	"	"	.090	4	2328		2328	2126		0
"	400	3¾	"	"	"	6	2064	1857.5	2064	"		0
"	Ice	Boxed	"	"	.125	4	2108		2108	"		0
"	400	3¾	"	"	"	4	2373		2373	"		1
Machine Countersunk Rivets:												
3/16	Ice	Boxed	1.5	1/3	.040	5	1029.5	528	792	555	362	0
"	400	3¾	"	"	"	9	744	595.5	647	"	"	0
"	Ice	Boxed	"	"	.063	9	1043.5	757	908	886	614	0
"	400	3¾	"	"	"	6	1030	781.5	896	"	"	4
"	Ice	Boxed	"	"	.090	9	1125	939.5	978	1035	842	2
"	400	3¾	"	"	"	8	1172	968.5	1019	"	"	7
1/4	Ice	Boxed	"	"	.063	4	1194.5	806	1039	1290	811	0
"	400	3¾	"	"	"	4	1496	845.5	1268	"	"	1
"	Ice	Boxed	"	"	.090	4	2018	1062.5	1594	1647	1053	0
"	400	3¾	"	"	"	4	1982.5	1093.5	1640	"	"	0
"	Ice	Boxed	"	"	.125	4	2079.5	1635.5	1810	1877	1357	0
"	400	3¾	"	"	"	4	2180	1838	1895	"	"	1

Note: All the above rivets were Squeeze driven with a Cone Point set

TABLE 9

MACHINE COUNTERSUNK RIVETS IN LAP JOINTS OF CLAD 7075-T6 SHEET

Rivet Size	Aging Temp °F	Aging Time-Hrs	Diam. of Driven Head	Protrusion in Shank Diams.	Sheet Thickness	Number of Tests	Average Test Ultimate Lbs.	Average Test Yield Lbs	Test Design Ult. Lbs.	ANC-5 Values Ult. in Lbs.	ANC-5 Values Yield in Lbs.	Rejectable Cracked Rivets
3/16	Ice Boxed		1 1/3	1.08	.071	3	1119	732.5	973	942	669	0
3/16	400	3 3/4	1 1/3	1.08	.071	3	1132.5	726.5	985	942	669	0
3/16	400	3 3/4	1 1/3	1.25	.071	3	1175	681	1022	942	669	0
3/16	400	3 3/4	1 1/3	1.58	.071	3	1156.5	496.5	745	942	669	0
1/4	400	3 3/4	1 1/3	1.18	.090	6	1850	1021	1531	1647	1053	0

Note: All the above rivets were squeeze driven with a Cone Point set

TABLE 10

2024 RIVETS IN LAP JOINTS OF ALUMINUM ALLOY SHEET

Rivet Size	Aging Temp °F	Aging Time-Hrs	Sheet Material	Sheet Thickness	Number of Tests	Average Test Ultimate Lbs	ANC-5 Design Ultimate Lbs.
1/8	405	4 3/4	7178-T6	.025	6	479	512.5
5/32	"	"	not known	.063	6	883	814
3/16	"	5	7178-T6	.072	6	1140	1175
1/4	"	"	7075-T6	.092	6	2015	2126

Notes: All rivets were Protruding
These specimens were made in Plant 2 by Mfg. R + D

TABLE II

2024 RIVETS IN LAP JOINTS OF CLAD 7075-T6 SHEET

Rivet Size	Aging Temp. °F	Aging Time-Hrs	Diam. of Driven Head	Protrusion in Shank Diams	Sheet Thickness	Number of Tests	Average Test Ultimate Lbs.	Average Test Yield Lbs.	Test Design Ult. Lbs.	ANC-5 Values Ult. in Lbs	ANC-5 Values Yield in Lbs	Rejectable Cracked Rivets
Protruding Head Rivets:												
3/16	395	3¾	1.3 - 1.4	1.05 - 1.15	.040	6	952.5		952.5	1142		0
"	"	"	"	"	.063	6	1385		1385	1175		0
"	"	"	"	"	.090	6	1429		1429	1175		0
1/4	"	"	"	"	.063	6	1974		1974	2050		0
"	"	"	"	"	.090	6	2149		2149	2126		0
"	"	"	"	"	.125	6	2369.5		2369.5	2126		0
Machine Countersunk Rivets:												
3/16	395	3¾	1.3 - 1.4	1.05 - 1.15	.040	6	856.5	307	460	553	362	0
"	"	"	"	"	.063	5	1096.5	557	835	886	614	2
"	"	"	"	"	.090	6	1194.5	669	1003	1035	842	0
1/4	"	"	"	"	.125	6	2341.5	1525.5	2036	1877	1357	0

Note All the above rivets were squeeze driven with a Cone Point set
Some had smaller flush heads than normal
Some of the rivet holes were chamfered under the Cone Point heads

TABLE 12

2024 RIVETS SQUEEZED TO FORM LAP JOINTS OF CLAD 7075-T6 SHEET

Rivet Size	Aging Temp. °F	Aging Time-Hrs	Diam. of Driven Head	Protrusion in Shank Diam.	Sheet Thickness	Number of Tests	Average Test Ultimate Ksi.	Average Test Yield Ksi.	Test Design Ult. Ksi	ANC-5 Values Ult. in Ksi	ANC-5 Values Yield in Ksi	Rejectable Cracked Rivets
Protruding Head Rivets:												
3/16	Ice	Boxed	1.54	1.4	.040	4	39.1		39.1	39.85		0
"	395	3¾	1.53	1.4	"	4	40.2		40.2	"		6
"	Ice	Boxed	1.50	1.33	.063	9	41.1	37.4	41.1	41.0		0
"	395	3¾	1.50	1.33	"	9	43.9	40.0	43.9	"		13
"	Ice	Boxed	1.58	1.36	.090	9	41.7	39.5	41.7	"		5
"	395	3¾	1.49	1.36	"	9	44.6	42.3	44.6	"		7
1/4	Ice	Boxed	1.42	1.25	.063	5	38.5	34.9	38.5	39.52		0
"	395	3¾	1.44	1.25	"	5	38.2	34.5	38.2	"		0
"	Ice	Boxed	1.39	1.28	.090	4	42.2		42.2	41.0		0
"	395	3¾	1.45	1.28	"	4	38.9		38.9	"		0
"	Ice	Boxed	1.41	1.25	.125	4	42.8		42.8	"		0
"	395	3¾	1.42	1.25	"	4	44.2		44.2	"		0
Machine Countersunk Rivets												
3/16	Ice	Boxed	1.47		.040	5	33.7	16.5	24.75	19.37	12.64	0
"	395	3¾	1.47		"	5	23.0	17.8	20.0	"	"	2
"	Ice	Boxed	1.47		.063	9	34.8	25.2	30.25	30.9	21.44	0
"	395	3¾	1.45		"	9	34.4	26.0	29.9	"	"	2
"	Ice	Boxed	1.49		.090	9	37.5	31.1	32.6	36.14	29.36	0
"	395	3¾	1.47		"	9	39.2	32.1	34.1	"	"	7
1/4	Ice	Boxed	1.34	1.25	.063	4	37.1	15.0	22.5	24.86	15.63	0
"	395	3¾	1.38	1.25	"	4	27.8	15.7	24.2	"	"	0
"	Ice	Boxed	1.39	1.29	.090	4	37.5	20.1	30.15	31.94	20.3	1
"	395	3¾	1.45	1.29	"	4	36.6	20.4	30.6	"	"	0
"	Ice	Boxed	1.40	1.25	.125	4	38.6	30.4	33.55	36.18	26.14	0
"	395	3¾	1.42	1.25	"	4	40.6	34.1	35.28	"	"	1

TABLE 13

2024 RIVETS IN LAP JOINTS OF CLAD 7075-T6 SHEET

Number of Heat Treats	Aging Temp. °F	Aging Time-Hrs	Depth of Countersink	How Driven	Driving Set	Number of Tests	Average Test Ultimate Lbs.	Average Test Yield Lbs	Test Design Ult. Lbs	ANC-5 Values Ult. in Lbs.	ANC-5 Values Yield in Lbs.	Rejectable Cracked Rivets
Protruding Head Rivets												
1	395	3¾		Squeezed	Cone	6	1125		1125	1142		0
1	395	3¾		Gun	Flat	6	1127		1127	1142		0
Machine Countersunk Rivets:												
1	Ice Boxed		.040	Squeezed	Cone	6	1201	746	1044	555	362	0
1	"	"	.040	Gun	Flat	6	1130	705.5	982	"	"	0
1	"	"	.070	Squeezed	Cone	6	824	346	519	"	"	0
1	"	"	.070	Gun	Flat	6	837.5	342	513	"	"	0
1	395	3¾	.040	Squeezed	Cone	6	1045	515.5	763	"	"	0
3	"	"	"	Squeezed	Cone	6	1058	533	800	"	"	0
1	"	"	"	Gun	Flat	6	1094	678	952	"	"	0
3	"	"	"	Gun	Flat	6	1032	586	879	"	"	0
1	"	"	.070	Squeezed	Cone	6	612	353	530	"	"	0
3	"	"	"	Squeezed	Cone	6	595	327	490	"	"	0
1	"	"	"	Gun	Flat	6	685	183	275	"	"	0
3	"	"	"	Gun	Flat	6	754	213	320	"	"	0

Notes: All tests were made with 3/16" -rivets in .040 clad 7075-T6 sheet
All heat treatments were complete, ie. solution heattreatment plus aging.
All shank protrusions were between 1.05 and 1.15 shank diameters
All rivet head diameters were between 1.33 and 1.40 shank diameters.

TABLE 14
SUMMARY OF AGING EFFECTS

Aging Temp. °F	Aging Time-Hrs.	% That Did Not Meet ANC-5	% Rivets That Had Rejectable Cracks	Number of Test Specimens
Ice Boxed		20.8	3.51	644
395	3¾	59.9	13.90	212
395	4	2.0	9.71	449
395	5	0.0	12.50	4
395	6	0.0	37.50	4
400	3¾	31.4	15.70	86
400	4¾	100.0	45.80	24
405	4	0.0	0.00	2
405	4¼	23.6	4.61	437
405	4½	100.0		33
405	4¾	50.0		12
405	5	33.3	23.2	36
405	5¼	100.0		24
405	6	0.0	12.5	4
415	3	0.0	0.0	2
415	4	0.0	0.0	4
415	4½	25.0	22.5	20
415	5	0.0	37.5	4
425	3	0.0	0.0	2
425	4	0.0	25.0	4
425	5	100.0	0.0	4